Biophysical Analysis of Biosignals: Theoretical Background

K. Kozlíková
Biosignal

- During the process of diagnosis, it is necessary to obtain information about the patient's condition.
- Information about functioning of an organism is encoded in its analogue manifestation.
- Material carrier of the information is a signal.
- **Biological signal** (biosignal) is any material manifestation of information on an investigated biological system.
- **Biosignals** improve the characteristic of a given system, therefore, they form the basis of all diagnostic methods.
Displaying and recording measured values

- Processing of biosignals
  - Receiving biosignal
  - Amplification and pre-processing of signals
  - Displaying and saving of measured values of biosignals
    - From the point of view of form
      - Numerical
      - Pictorial
      - Graphical
    - From the point of view of archiving period
      - Transient
      - Permanent
Analysis of biosignals

- From the point of view of output
  - Qualitative
    - Visual
      - The output is a narrative description
  - Quantitative
    - Measurement of physical quantities
      - The output are numbers

- From the point of view of signal complexity
  - Automatic
    - Particularly irregular, complex, non-repetitive signals
  - Manual
    - Simple, repetitive signals

Therefore, during practical training analysis of an ECG record
Biophysical analysis of an electrocardiogram (1)

- Electrocardiographic curve
  - Graphical record of the electric activity of the heart (permanent)
  - Relatively simple graph of the dependence of electric voltage on time
  - Quasi-periodic (almost periodic) curve
    - A part of the record repeats regularly (or with only minor changes)

An example of an ECG record of one lead.
Source: author's archive
Biophysical analysis of an electrocardiogram (2)

- Biophysical analysis of an ECG curve
  - Simple
    - Amplitude
      - Measurement of height of individual deflections
    - Time
      - Measurement of duration of individual parts of the ECG curve
  - Frequency
    - Establishing (mean) heart rate
  - More complicated
    - Related to values obtained from simple analysis
      - Construction of electric heart axis
      - Analysis of heart rate variability
    - Using special software
      - Spectral (frequency) analysis of ECG
Biophysical principle of the electrocardiogram

- The heart functions as a pump – it expels blood into the circulatory system.
- The function of the piston is represented by the contracting ventricular muscle.
- Coordination of contraction is provided by the sequence of action potentials – sources of electric current – electric heart field is created.
- The heart as a source of electric current is placed in the human body – electric conductive medium – three-dimensional volume conductor that modifies the electric heart field.
- Electric heart field is registered at the body surface as electric voltage – potential difference – in form of electrocardiographic curves.
Physical comment - electric voltage

Electric voltage

- Physical quantity
  - Expresses the difference of the electric potential between two points
  - Represents the energy needed to displace the electric charge between these two points in a certain electric field
  - Symbol: $U$
  - SI unit: Volt [V]

- Is related to the electric current $I$ [A] (movement of electrical charges) in agreement with Ohm’s law
  \[ U = R \cdot I \]

- $R$: electric resistance [Ω]

An example of a simple electric circuit to measure the voltage using a voltmeter.
Electrocardiography – basic terminology

- **Electrocardiography**
  - A method of detection, recording and analyses of action potentials of the heart (as being transferred to the body surface)

- **Electrocardiogram**
  - Graphical output of an electrocardiograph that records the electric activity (changes of electric voltage) of the heart during time

- **Electrocardiograph**
  - A device used to record the electric activity of the heart
Electrocardiographic leads

- A lead
  - Combination of two conductors and their electrodes, that form with the measuring device (electrocardiograph) a closed electric circuit
  - Bipolar
    - Two active (equivalent) electrodes
  - Unipolar
    - An active (different) and a reference (indifferent) electrode

Electrocardiograph and usually used electrodes for standard examination.
[Cit. 4. 4. 2011] Available at: http://produkt.sluzby.cz/elektrokardiograph-8738
Bipolar leads – Einthoven triangle

- Electric activity of heart
  - Electric dipole (about 90%)
- Heart position
  - In frontal plane
  - In the middle of an equilateral triangle
- Position of electrodes
  - Right hand (R)
  - Left hand (L)
  - Left foot (F)
- Symbols of leads (bipolar)
  - I: \( V_I = \Phi_L - \Phi_R \)
  - II: \( V_{II} = \Phi_F - \Phi_R \)
  - III: \( V_{III} = \Phi_F - \Phi_L \)
- In each instant is valid for voltage \( V_i \) (Einthoven's rule)
  \[ V_I + V_{III} = V_{II} \]
  \( \Phi_i \) : electric potential on the \( i^{th} \) electrode
Wilson central terminal

- Reference electrode pre unipolar leads
- Connection through large electric resistances
  - The total current in the Wilson central terminal has to be zero
  - 1st Kirchhoff law

\[ I_R + I_L + I_F = 0 \]

\[ \frac{\Phi_{WS} - \Phi_R}{5000} + \frac{\Phi_{WS} - \Phi_L}{5000} + \frac{\Phi_{WS} - \Phi_F}{5000} = 0 \]

- \( \Phi_i \): potential at \( i^{th} \) electrode
- Potential at the Wilson central terminal
  - Average potential of limbs

\[ \Phi_{WS} = \frac{\Phi_R + \Phi_L + \Phi_F}{3} \]
Unipolar leads - limbs

- Formation
  - Disconnection of one electrode from the Wilson central terminal
- Names and symbols of unipolar leads
  - Augmented (amplified) – aVR, aVL, aVF
    - According to the disconnected electrode
  - Goldberger leads

Unipolar leads - chest

- **Standard positions – six leads:**
  - $V_1, V_2, V_3, V_4, V_5, V_6$
  - Standard, well defined positions in the 4th and 5th intercostal space

- **Next used locations:**
  - $V_7$
    - Posterior axillary line
  - $V_3R, V_4R, V_5R, V_6R$
    - „Mirror image“ $V_3, V_4, V_5, V_6$

Chest leads and their standard positions.
Standard 12-lead electrocardiogram (1)

- Displayed are leads I, II, III, aVR, aVL, aVF (left) and V₁ to V₆ (right)
- At the beginning of every lead is the calibration deflection
- Below the curves is paper speed, voltage calibration, registered frequency band of signals and the heart rate
- Source: author's archive
Standard 12-lead electrocardiogram (2)

- Displayed are the leads I, II, III, aVR, aVL, aVF (left) and V₁ to V₆ (right)
- At the beginning of the limb lead is a calibration deflection valid also for the chest lead
  - For leads V₅ and V₆ an appropriate calibration was used – the curves overlap
- Time calibration is missing
- Source: author’s archive
Basic terminology of an ECG curve

TP segment is used as zero isoelectric line (zero voltage).

Electrocardiographic terminology. [Cit. 30. 3. 2011] Available at: http://nursingpub.com/12-lead-ekg-explained-part-1
Polarity and height of deflection

- **Polarity of deflection**
  - Depends on mutual position of the depolarisation wave and the recording electrode

  ![Diagram showing basic forms of QRS complex according to polarity](http://drkupe.blogspot.com/2011/03/ecg.html)

- **Height of deflection**
  - Depends on mutual distance of the depolarisation wave and the recording electrode
  - It is the higher the closer they are

- **Depolarisation wave**
  - Boundary between polarised and depolarised areas, the direction of depolarisation
Positive and negative waves

- Always positive:
  - Wave R

- Always negative:
  - Wave Q
    - Precedes the R wave
  - Wave S
    - Follows the S wave

- Positive or negative:
  - P wave
  - T wave

Some possible shapes of QRS complex
Calibration of the graphic record (1)

- Electrocardiographic curve is recorded onto a special millimetre paper

- Time calibration – paper speed
  - Standard speed
    - 25 mm/s
      - 1 mm ⇔ 0.04 s
      - 5 mm ⇔ 0.2 s
  - Slower speed (for detailed analysis)
    - 50 mm/s
      - 1 mm ⇔ 0.02 s
      - 5 mm ⇔ 0.1 s
  - Faster speed (for heart rate analysis)
    - 10 mm/s
      - 1 mm ⇔ 0.1 s
      - 5 mm ⇔ 0.5 s
Calibration of the graphic record (2)

- Voltage calibration
  - Standard
    - 10 mm ⇔ 1 mV
      - 1 mm ⇔ 0.1 mV
  - For low deflections
    - 20 mm ⇔ 1 mV
      - 1 mm ⇔ 0.05 mV
  - For high deflections
    - 5 mm ⇔ 1 mV
      - 1 mm ⇔ 0.2 mV

Examples of different voltage calibration for limb leads (10 mm/mV) and for chest leads (5 mm/mV).
Source: author's archive
Heart rate (1)

- The pressure wave that passes during the heart activity through the arterial part of the vascular system, is called heart rate (pulse) and is palpable on the arteries.
- This series of waves corresponds to the heart rate and frequency.
- Measurement of heart rate
  - Palpation method – „on-line“
    - Common way
    - Is considerably subjective
  - Based on an electrocardiographic curve – „off-line“
    - Duration of RR interval
    - More exact measurement

\[
SF \ [\text{min}^{-1}] = \frac{60}{RR \ [s]}
\]
Heart rate (2)

- Heart rate of a healthy person is in average 70 beats/min
  - Physiologic values are 60 beats/min to 90 beats/min
    - Bradycardia – less than 50 beats/min
    - Tachycardia – more than 100 beats/min
- Values can change depending on
  - Age
  - Body size
  - Cardiac problems
  - Physical activity
- In persons breathing normally, the heart rate changes
  - Sinus arytmia - physiologic phenomenon
    - Increases during inspiration
    - Decreases during expiration
Electrical heart axis (1)

- Represents the dominant direction of propagation of heart activation (not the heart position)
- Direction (orientation) of a vector, that is the sum of all partial vectors during depolarisation
- Mean electric heart vector
- Can be evaluated
  - In a particular time instant (1, 2, 3, 4)
  - During a particular time interval (1+2+3+4)
    - During QRS complex
    - During T wave
    - During P wave
Electrical heart axis (2)

- Usually evaluated in the frontal plane
- Based on
  - Einthoven triangle
  - **Hexaxial reference (Bailey) system**
    - Sides of the Einthoven triangle are shifted into its middle

Axial reference system in frontal plane.
[Cit. 30. 3. 2011]. Available at: http://www.cvphysiology.com/Arrhythmias/A013a.htm
Electrical heart axis (3)

- Is expressed as an angle measured in degrees from the horizontal axis directed from right to left
  - Types of electrical heart axis
    - Normal
      - -30° to 100°
    - Left axis deviation
      - -90° to -30°
    - Right axis deviation
      - 100° to 180°
    - Extreme right axis deviation
      - -90° to -180°
  - Position of electrical heart axis
    - Horizontal
      - -30° to 30°
    - Vertical
      - Around 90°
    - Intermediate
      - 30° to 60°

Electrical heart axis. [Cit. 30. 3. 2013] Available at: http://www.blobs.org/science/article.php?article=87
Electrical heart axis (4)

- Simple visual evaluation based on amplitudes of limb leads
  - I, II, III
  - aVR, aVL, aVF
- Basic principle of construction
An ECG ruler – a tool for ECG analysis

- Different versions
  - Always contain
    - Millimetre scale
    - Deflections
    - Time intervals
  - Heart rate scale
  - Time calibration

- May contain
  - Conversion of values
  - Hexaxial system for electrical heart axis evaluation
  - Protractor
  - ECG curve
  - Other data
Used and recommended literature

Lectures available at MEFANET portal, English version, part Biophysics (http://portal.fmed.uniba.sk/):
K. KOZLÍKOVÁ: Overview of Biological Signals.
K. KOZLÍKOVÁ: Active Electric Biosignals I.
K. KOZLÍKOVÁ: Active Electric Biosignals II.

J. MALMIVUO, R. PLONSEY: Bioelectromagnetism - Principles and Applications of Bioelectric and Biomagnetic Fields.